

Search for RS-gravitons at CDF

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Abstract. We present a search for Randall-Sundrum (RS) gravitons decaying to diphotons or dielectrons or dimuons, performed with the CDF II detector and using up to 5.7 fb^{-1} of integrated luminosity. The respective mass spectra are consistent with the ones expected by the standard model. For the RS-model parameter $k/\bar{M}_{Pl} = 0.1$, RS-gravitons with mass less than $1111 \text{ GeV}/c^2$ are excluded at 95% CL.

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INTRODUCTION

Although extremely successful, the standard model (SM) of particles and fields is not sufficient for solving many open physics problems including the source of the dark matter, the incorporation of gravity, and the hierarchy problem between the weak and Planck scales. One theory that addresses the hierarchy problem is the Randall-Sundrum (RS) graviton model [1].

The RS model solves the hierarchy problem by introducing an extra compact dimension accessible only to gravity. The phenomenology leads to a small number of distinct Kaluza-Klein states (spin-2 gravitons) that couple with gravitational-strength to SM particles and can be detected as resonances of pairs of jets, leptons, photons, or W/Z bosons. Given the considerable dijet background in a hadron-collider environment, and the low leptonic branching fraction of the weak bosons, the prompt dilepton and diphoton final states offer the greatest sensitivity at the Tevatron. We present here the recent CDF searches for RS-gravitons decaying to diphotons, dielectrons, or dimuons.

SEARCH FOR RS-GRAVITONS DECAYING TO DIPHOTONS

For the 5.4 fb^{-1} diphoton search [2] a combination of two diphoton ($E_T > 12, 18 \text{ GeV}$) and two single-photon ($E_T > 50, 70 \text{ GeV}$) triggers is used. The two photon candidates are required to be central and fiducial in the detector, have $E_T > 15 \text{ GeV}$ and excess energy around a cone of $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ less than 2 GeV .

The expected number of RS graviton events, as a function of graviton mass, is estimated using the PYTHIA [3] Monte Carlo (MC) event generator, with CTEQ5L [4] parton distribution functions (PDF), and processed by the GEANT-based [5] CDF II detector simulation.

The main SM diphoton background to the graviton signal is the $\gamma\gamma$ production, determined using DIPHOX [6] next-to-leading order (NLO) MC event generator, with

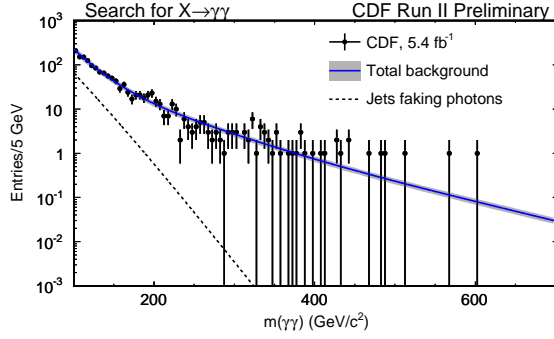


FIGURE 1. Diphoton mass spectrum from the CDF search for RS-gravitons.

acceptance corrected using a PYTHIA SM diphoton sample passing the CDF detector simulation, and with the high-mass spectrum extrapolated. A secondary background comes from jet+ γ or dijet events where one or two jets are misidentified as photons (fake-photon background). This background is determined with the construction of a CDF “fake diphoton” sample with looser photon identification requirements, to allow for jet contamination. Subsequently, the actual CDF diphoton spectrum is fitted to this “fake diphoton” shape along with the MC-estimated SM diphoton spectrum, with both components varying in the fit.

Systematic uncertainties arise from the luminosity determination (6%), the initial and final radiation (4-8%), and the Q^2 and PDF uncertainties (20%) in the DIPHOX calculation.

Figure 1 shows the observed diphoton mass spectrum with the total background overlaid. In the region around 200 GeV/c^2 there is an excess of events, with a local probability of such a fluctuation of 1.3%. This is consistent with the 1-sigma spread of minimal probabilities in the range of 150-650 GeV/c^2 , as determined with pseudoexperiments.

SEARCH FOR RS-GRAVITONS DECAYING TO DILEPTONS

CDF completed searches for the RS-gravitons in the dielectron [7] and dimuon [8] channels using 5.7 fb^{-1} of integrated luminosity. Single-lepton triggers requiring an electron or muon with transverse momentum $p_T > 18 \text{ GeV}/c$ are used, in addition to a trigger that remains efficient for $p_T > 70 \text{ GeV}/c$ electrons. Offline two electrons (muons) are selected, at least one with energy (p_T) above 20 GeV (GeV/c). The leptons come from the same primary vertex and are isolated, i.e., the excess energy in a cone $\Delta R = 0.4$ around each lepton is less than 10% of the energy (momentum) of the electron (muon). Cosmic veto and photon-conversion removal are applied; no opposite charge is enforced.

Main SM dilepton background to the RS-graviton dilepton signal is the Drell-Yan (DY) process $q\bar{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$. Significant background comes from QCD-originated events of one real lepton and one “fake” lepton, i.e., jet (track) faking an electron (muon). Minor backgrounds come from diboson (WW , WZ , ZZ , $W\gamma^*$) and $t\bar{t}$ processes with subsequent leptonic decays. The QCD background is determined with CDF data, with the application of a probability that a jet (track) fakes an electron (muon) on events with one

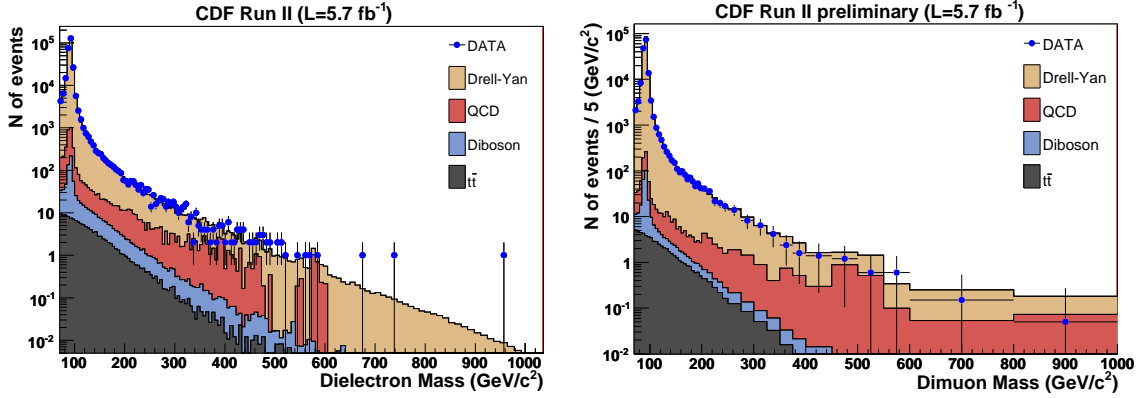


FIGURE 2. Dielectron and dimuon mass spectra from the CDF search for RS-gravitons.

identified lepton. This probability is a function of the jet's (track's) transverse momentum and is determined by counting reconstructed electrons and muons in a jet-rich CDF data, which is characterized by minimal leptonic content. All other backgrounds are estimated with MC simulations (PYTHIA-generated events using CTEQ5L PDF, processed by the CDF detector simulator) absolutely normalized to the theoretical next-to-leading order cross sections, data luminosity, lepton-ID scale factors and trigger efficiencies.

The main sources of systematic uncertainty on the MC-estimated backgrounds are the theoretical cross sections (an 8% effect on the event yields), the luminosity (6%), the lepton-ID efficiency (2%), the parton distribution functions (2%), and the trigger efficiency (0.5%). The total MC systematic uncertainty on the expected event yield is $\sim 10\%$. The respective QCD-background systematic uncertainty is $\sim 50\%$, which comes from the variation in the measurement of the fake probabilities using different jet-rich CDF datasets triggered with varied jet-energy thresholds.

The dielectron and dimuon mass spectra are consistent with expectation, as can be seen in Figure 2. At the same time, the highest-dielectron-mass event ever observed at the time was detected ($M_{ee} = 960 \text{ GeV}/c^2$). In this event, the two electrons have transverse momenta of 482 and 468 GeV/c and are oppositely charged. The event is characterized by very low hadronic activity (no jets are reconstructed) and by a low missing transverse energy of 17 GeV – separated by 23 degrees in ϕ from the 468 GeV/c electron – coming most probably from the resolution of the calorimeter. The probability that at least one event is observed with a mass at least that high is 4%. This probability is within the 1-sigma range of minimal probabilities observed anywhere in the dilepton spectrum, as determined by pseudoexperiments.

COMBINED LIMITS

The measured diphoton and dilepton spectra can be used to set a limit on RS-graviton production [8]. Here we parametrize the RS model using the mass of the lightest RS graviton (m_1) and the dimensionless parameter $\sqrt{8\pi}k/M_{Pl} \equiv k/\overline{M}_{Pl}$, where k is the curvature scale of the extra dimension and M_{Pl} is the Planck mass. RS-graviton signal

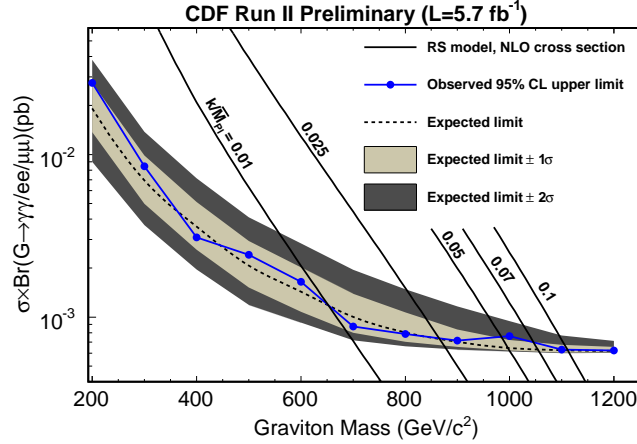


FIGURE 3. The 95% CL upper limit on the lightest RS-graviton production cross section, shown with theoretical cross sections for five values of k/\overline{M}_{Pl} .

MC events are generated using PYTHIA and values of m_1 from 200 to 1100 GeV/ c^2 . The signal-MC events are generated and normalized in the same manner as the background-MC events. The leading-order PYTHIA cross section is multiplied by a scale (“ K -factor”) to correct for next-to-leading-order effects [9].

Figure 3 shows the combined 95% CL cross-section ($\sigma \times \text{Br}(G \rightarrow \gamma\gamma/ee/\mu\mu)$) upper limit as a function of m_1 along with five theoretical cross-section curves for $k/\overline{M}_{Pl} = 0.01$ to 0.1, a theoretically interesting range that would provide a solution to the hierarchy problem. The limits are set using a frequentist method that compares the background-only with the signal+background hypotheses, taking into account correlated background systematic uncertainties across the channels [10]. The intersection of the cross-section exclusion limit with the theoretical cross-section curves gives the 95% CL lower limit on m_1 for the respective coupling. For $k/\overline{M}_{Pl} = 0.1$, the m_1 lower limit is 1111 GeV/ c^2 , if we use proper mass-dependent RS-graviton K -factors, and 1141 GeV/ c^2 assuming a fixed K -factor of 1.54, for comparisons with previous Tevatron results. For $m_1 > 1$ TeV/ c^2 , cross sections greater than 0.6 fb are excluded at the 95% CL. At the time of release, these results were the most stringent in the world.

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